Renewable Energy Forecasting

- Status and Challenges

- Client Needs

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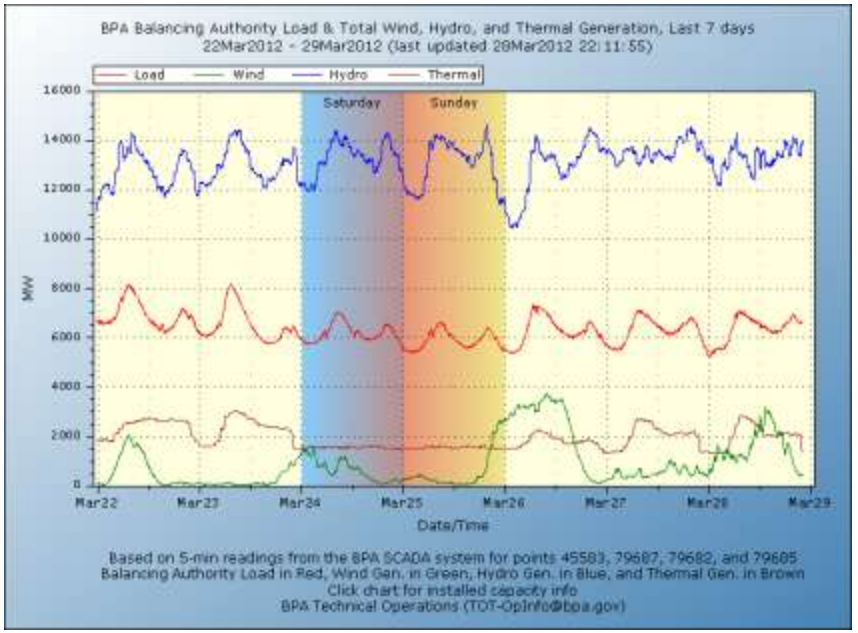
Effective Use of Renewable Energy Forecasts Lowers Overall System Costs and Enables Higher Penetration Levels

"As yet the wind is an untamed and un-harnessed force; And quite possibly one of the greatest discoveries hereafter to be made will be the taming and harnessing of the wind."

Abraham Lincoln
Bloomington, IL
April 4, 1858



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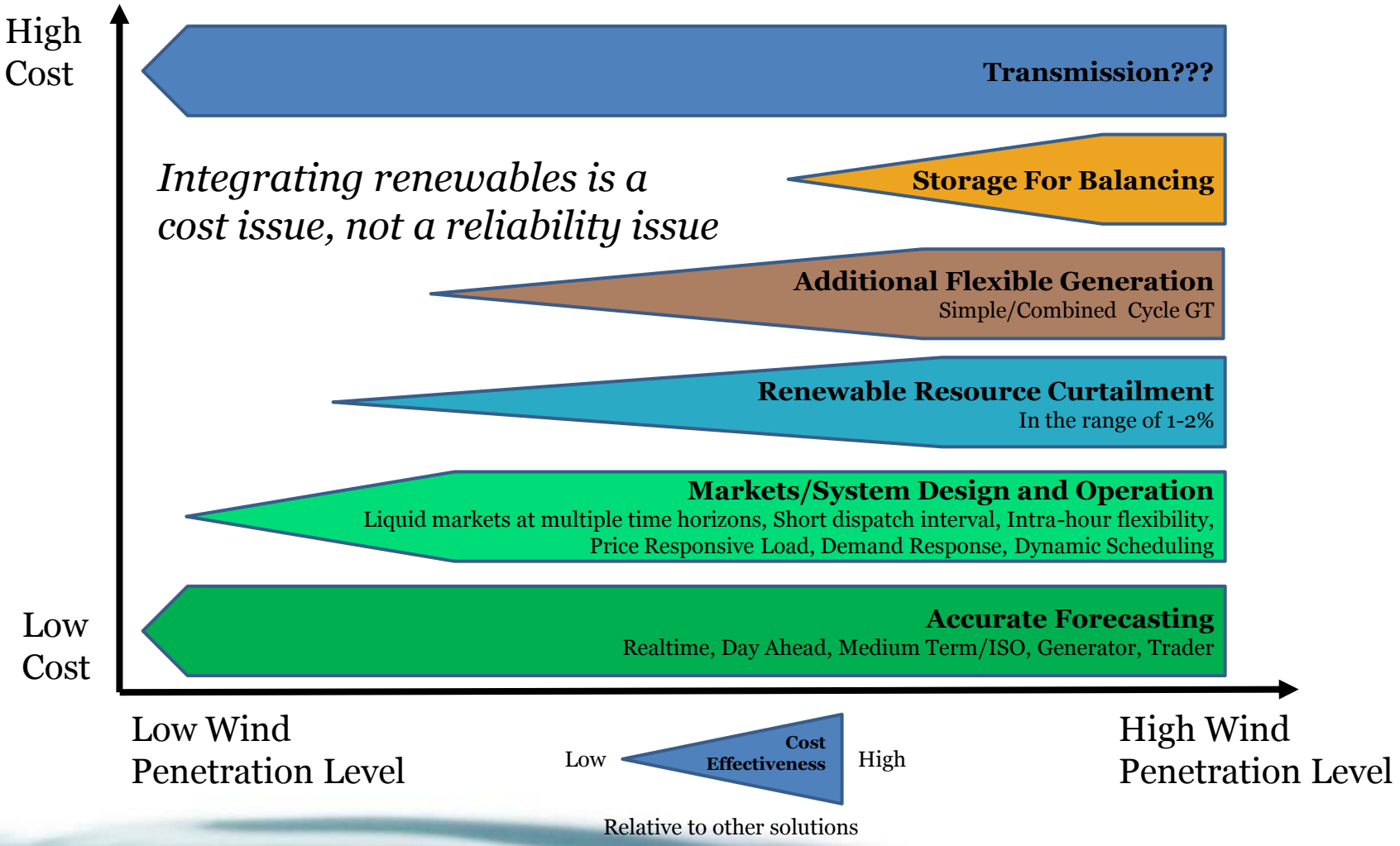
Renewable Integration Solutions



Why Forecast Renewable Energy?
The System Operator/BAA Perspective

- Reduces the amount of balancing reserves that need to be held
- Enables cheaper units to be committed
- Increases use of renewable units and reduces utilization of fossil units
- Reduces transmission curtailment and oversupply problems

Variable Generation Forecasts Increase Operational Efficiency Within A BAA, Reduce Overall Costs And Allow More Wind To Be Economically Integrated

Why Forecast Renewable Energy?
The Owner/Operator/Offtaker Perspective

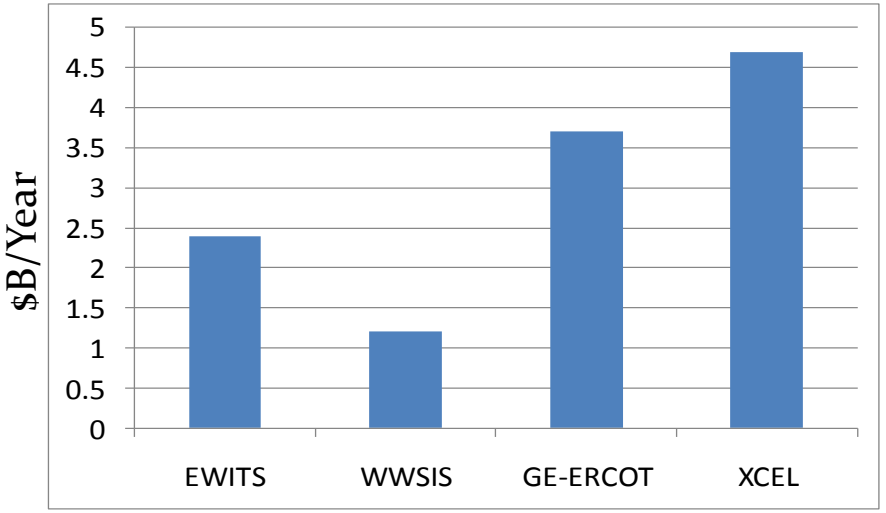
- See last slide! Reduces costs passed from BAA
- Allows wind generation to be traded/bid in/hedged
- Crucial to efficient operations and maintenance (and construction)
- Important for safe O&M – severe weather

Forecasts Increase The Value Of An Owner/Operators Generation Capacity And Ensure That It Is Utilized To The Greatest Extent Possible

Examples of Potential Savings

O&M Optimization

- A 100 MW wind farm delivers 2.4GWh per day at full power => $168K/day!
- A crane replacing a 55,000 lb gearbox can only operate in winds below 11 m/s
  - Possible costs if crane is mobilized at wrong time: $100K or more



Savings estimates for 20% wind using a perfect DA forecast instead of current SOA DA forecast .

Renewables Integration

- Costs estimated at between $3 and $12 / MWh
- That's $270 M to over $1B at today's relatively low penetration level!
- Improved forecasting accuracy, particularly in the short-range horizon will be a big driver in determining the cost of VER integration
- E.g. BPA proposed $12/MWh WIC for 2010/2011 rate period. Proof of better forecasting played a role in reducing this by over 50% saving $120 M+ in charges to wind over the rate period.

What determines the value of a wind forecast?

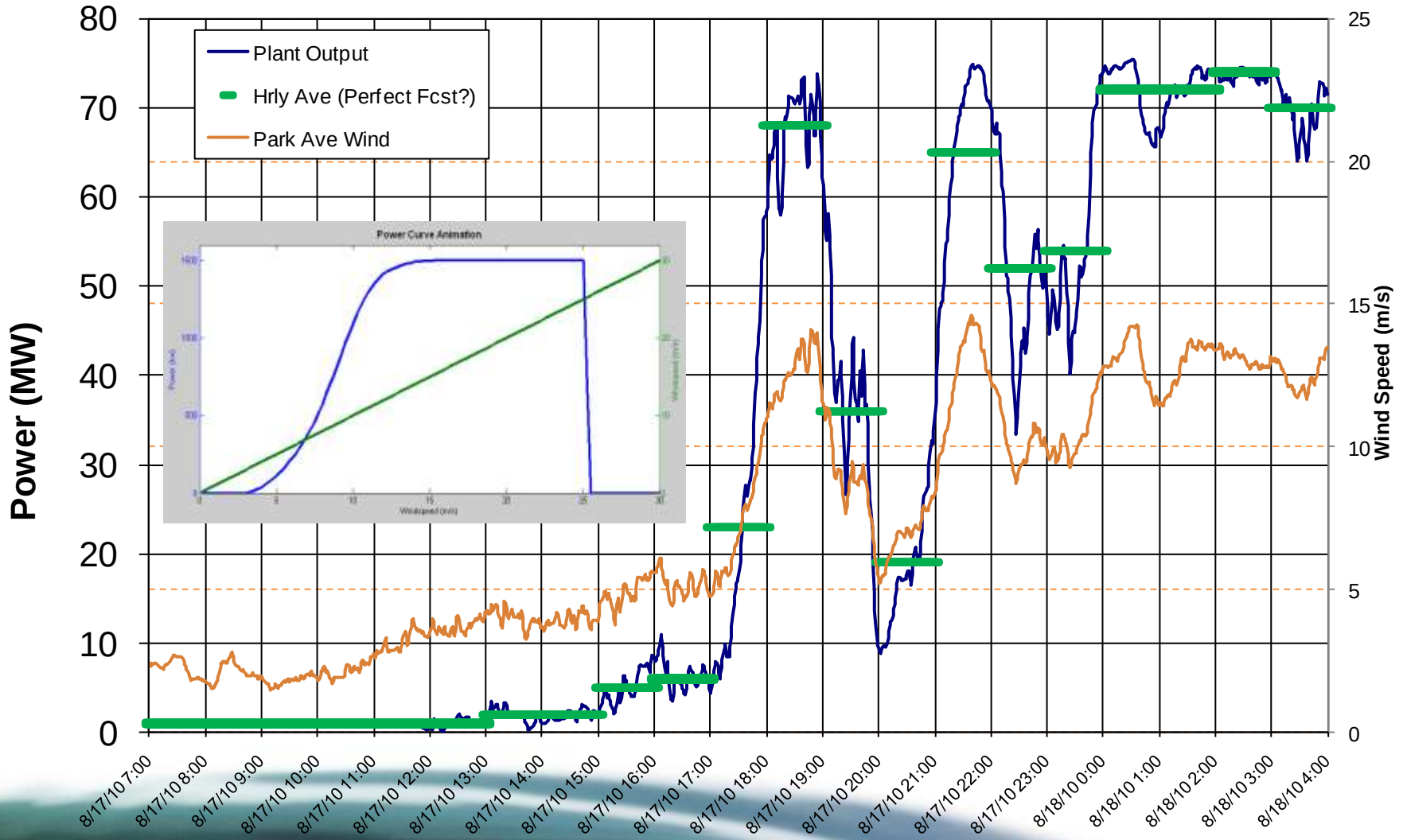
- Market design/rules and operating practices
- System operator charges, incentives and penalties
- Forecast **accuracy** and **reliability**
- Forecast **confidence** and a **reliable** measures of it
- Variability of the wind resource in time and space
- How the forecast is communicated and used

Forecasting Is Not A Silver Bullet

It Needs To Be Melded With Market/System Changes

That Maximize Benefits And Minimize Costs of VERs

Why Is Wind Forecasting Difficult?



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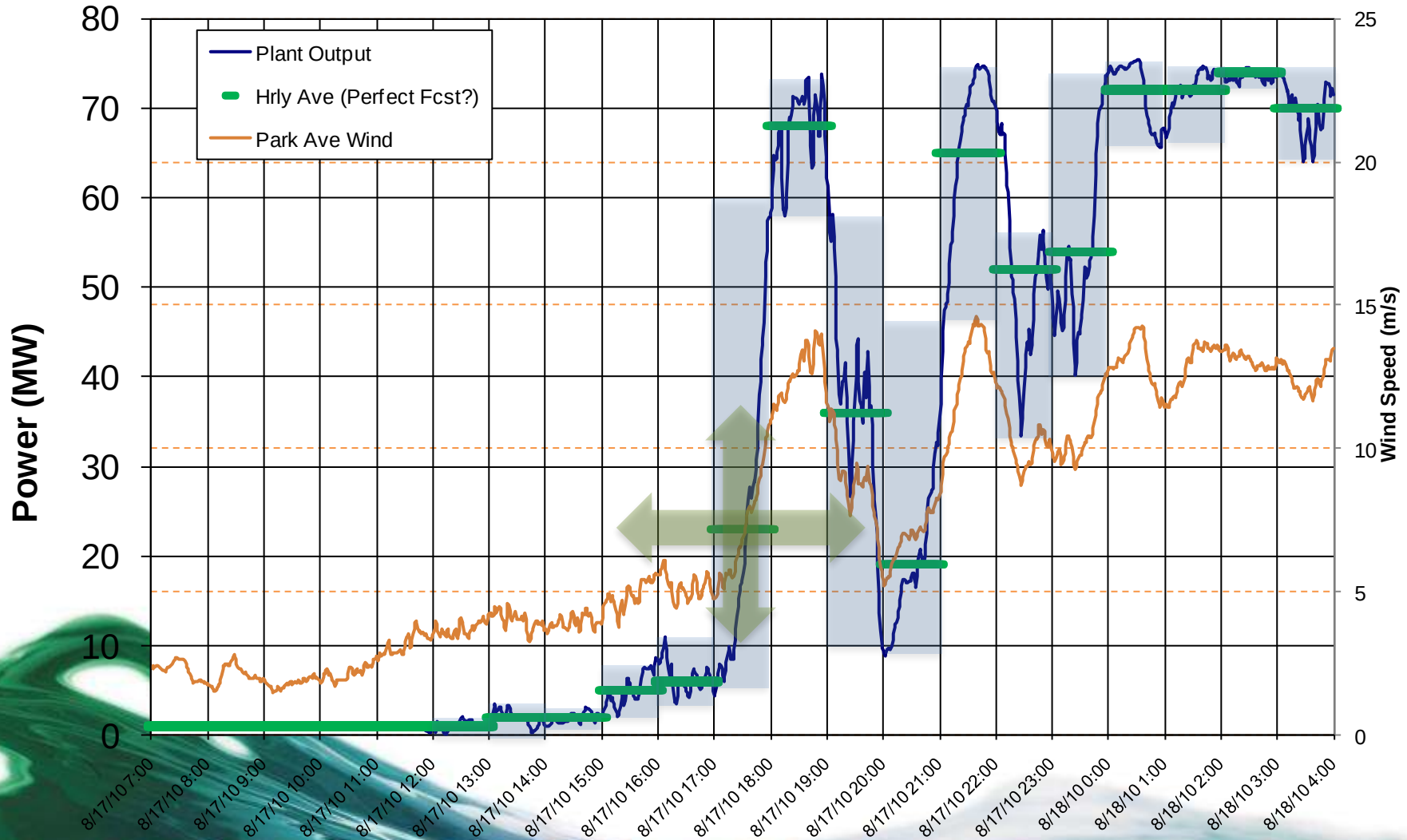
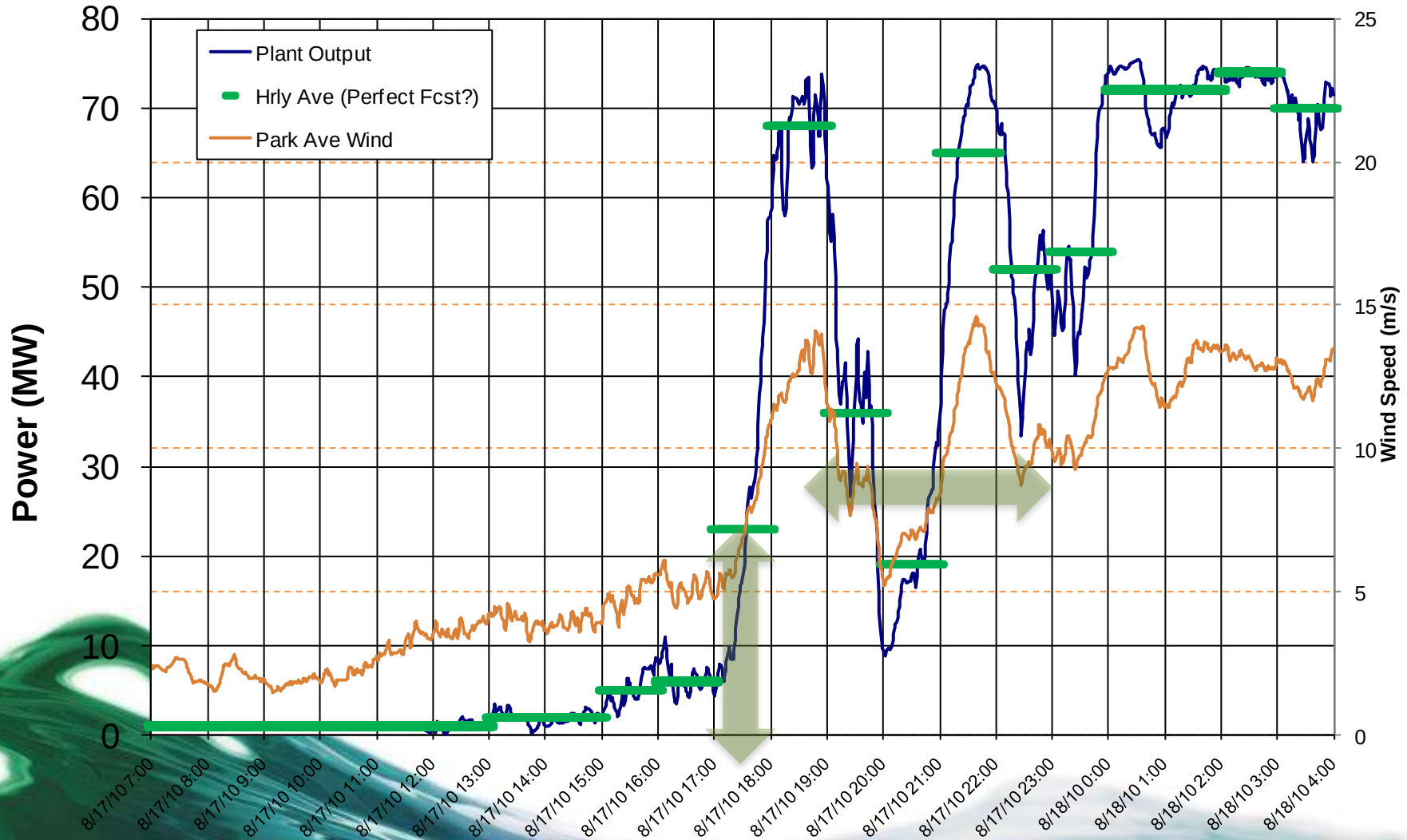
Variability and Uncertainty

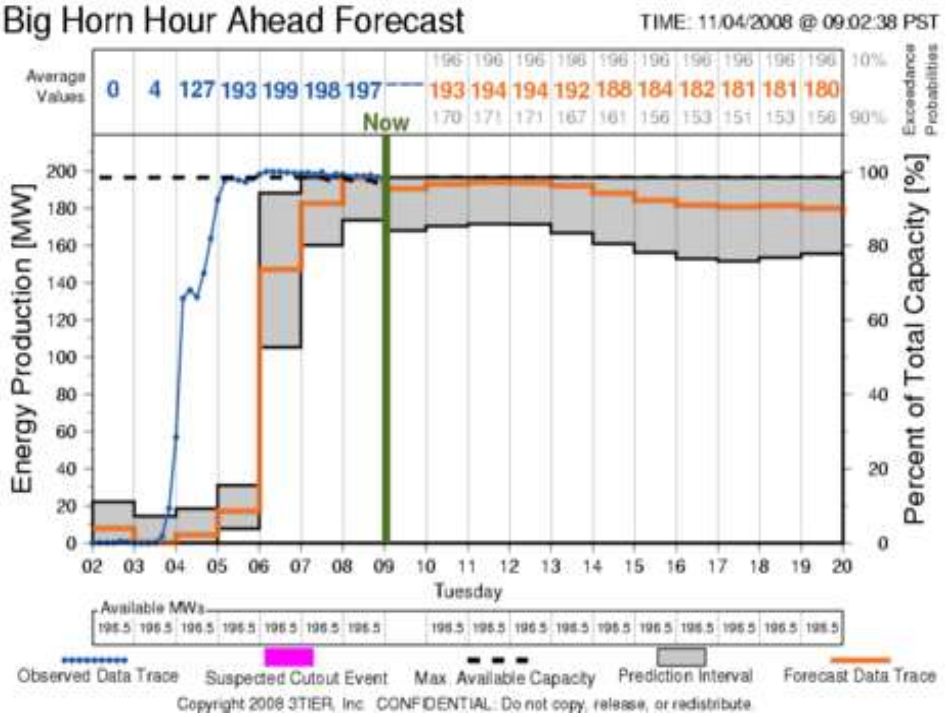


Variability and Uncertainty



Reliability in the Context of Variability and Uncertainty

- Variability cannot be removed by forecasting but impact can be reduced by a) knowledge, b) shorter scheduling intervals, c) diversity, d) storage
- Uncertainty is in forecasters realm. It can be reduced but never completely eliminated.
- Uncertainty is typically communicated using probabilistic confidence intervals
- Intervals describing variability and uncertainty need to be reliable when it matters. Often they are not.



Example above is illustrative only and typical of state-of-the-art. Author is not making any representation about reliability of confidence intervals of one vendor relative to any other.

Specific Challenges To Forecasting Ramp Events

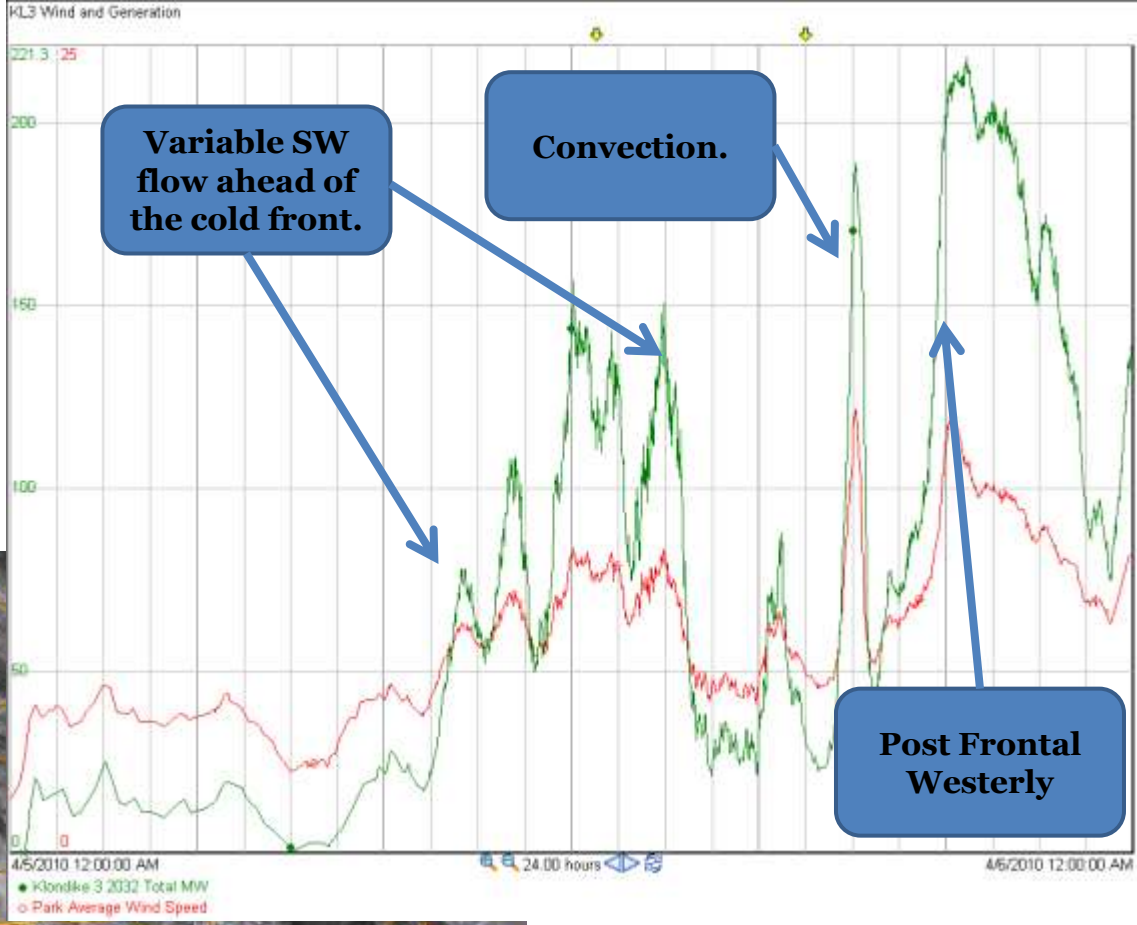
- Predicting atmospheric variables at the spatial and temporal scale required for renewable energy applications is pushing the envelope ramp or no ramp
- Ramps events highlight the limitations of models and are the biggest source of forecast failure because power curve mathematics magnify these limitations
- Ramps typically involve atmospheric phenomena and multiple scales. Typical causes some combination of :
  - Frontal systems, thunderstorms, mixing, terrain induced flow, thermally induced flow, low-level jets, extreme weather outside of machine operating range
- In general larger scale phenomena are easier to predict at longer lead times.

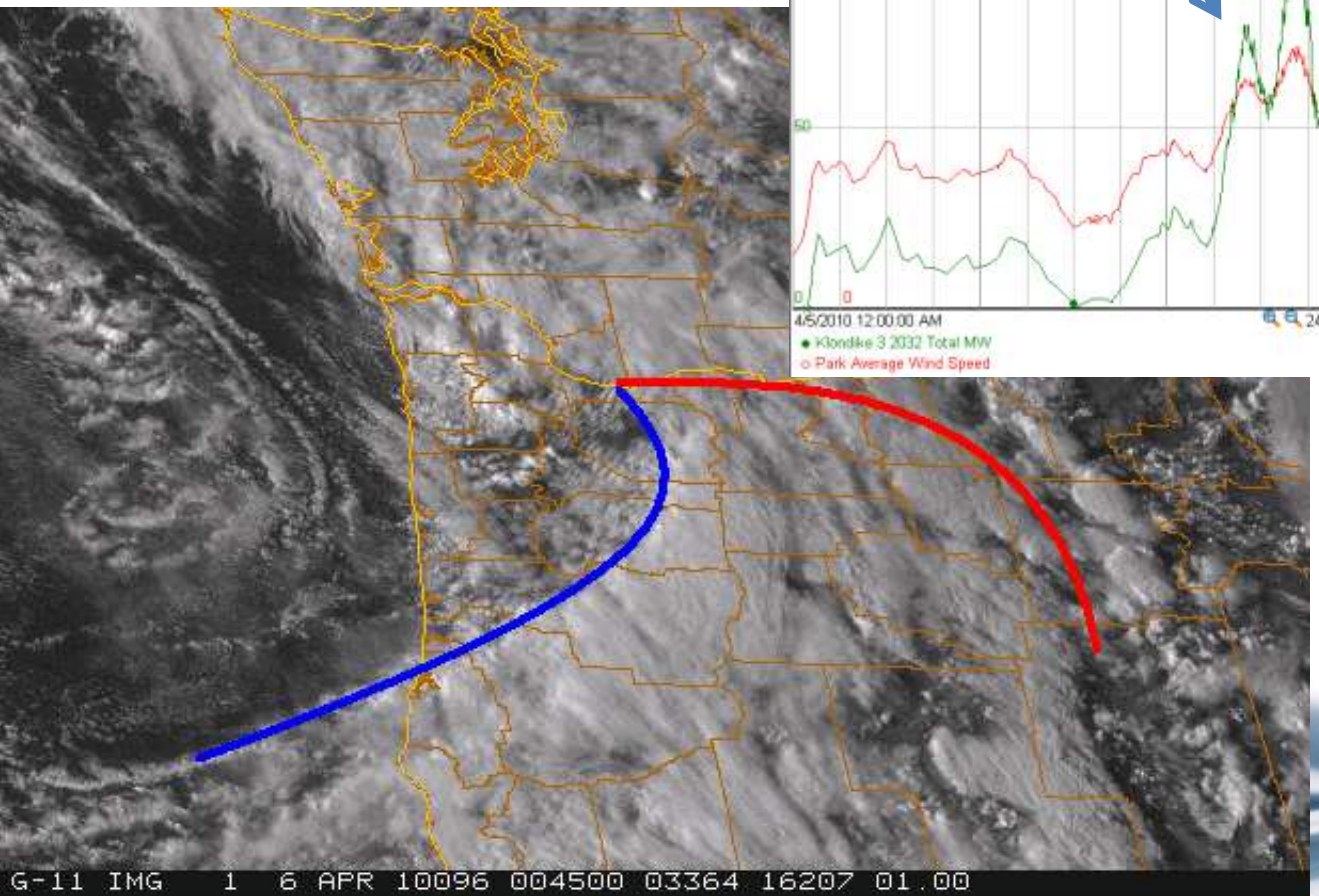
Multiple ramps associated with synoptic system and local scale mixing and terrain interactions

Key Characteristics: High spatial and temporal variability and complexity

Required approach: Hi-res probabalistic

Challenges: Data, data (vertical), assimilation, resolution (horiz and vert), ensembles and post-pro, parameterizations





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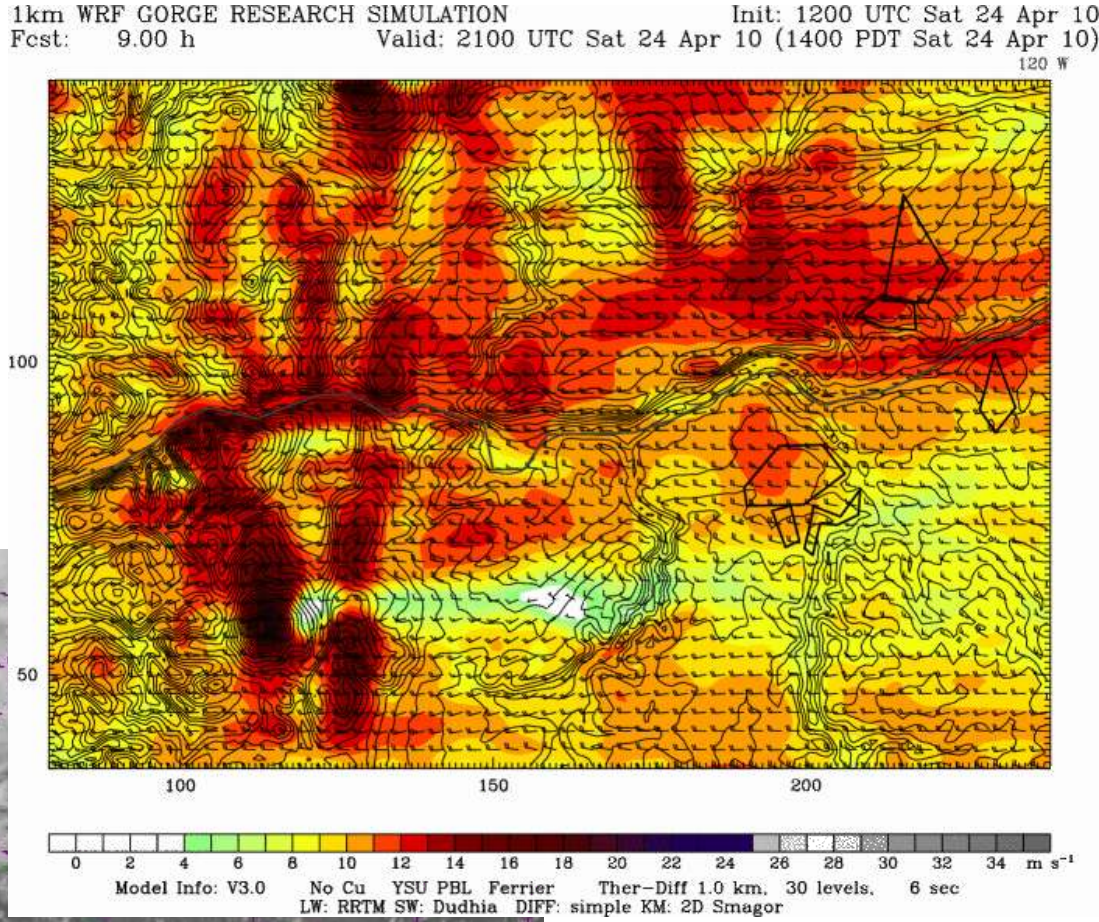
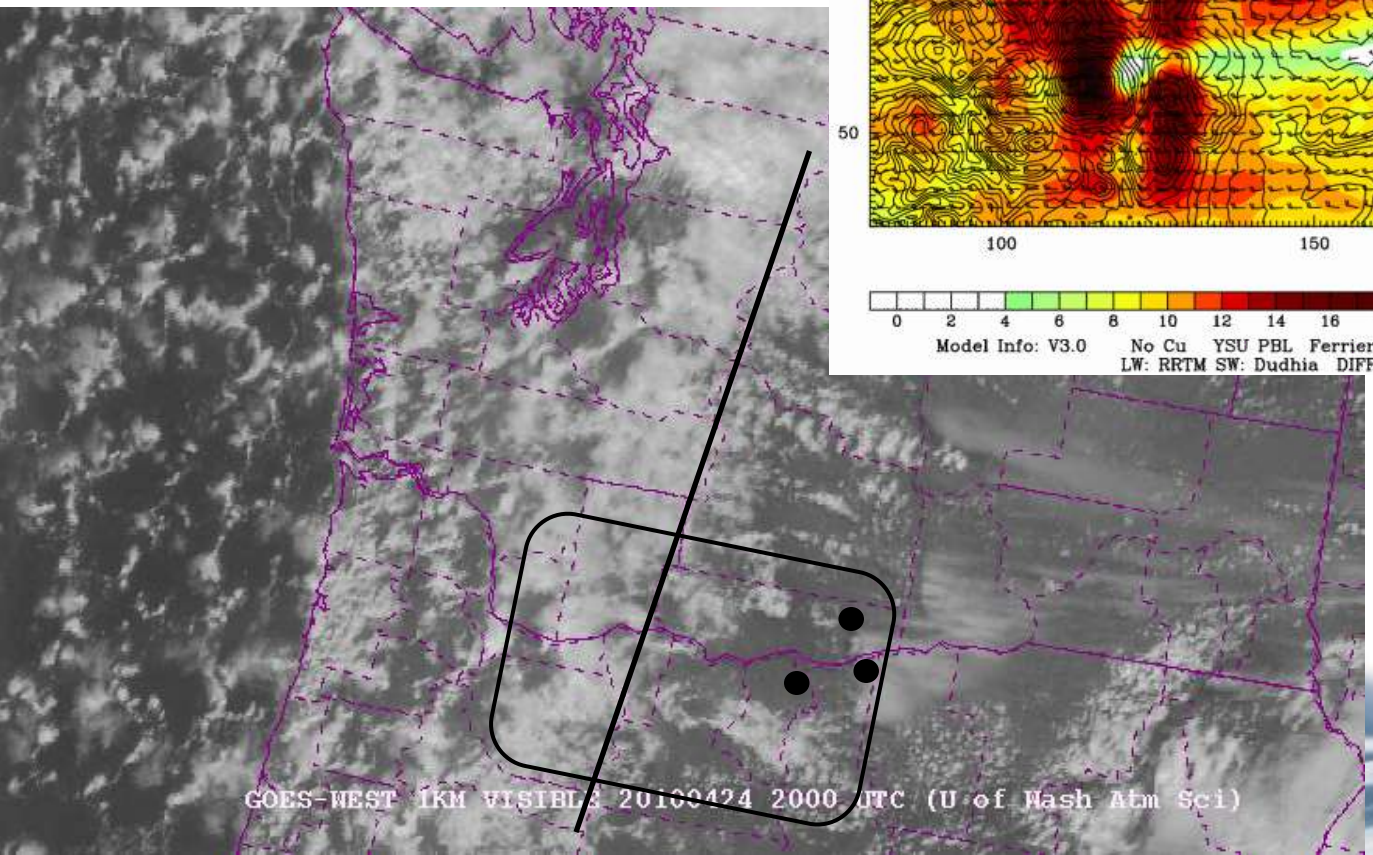
Post Frontal: Strong flow across The Cascades setting up mountain waves.

Key Characteristics: High spatial and temporal variability and complexity

Required approach: Hi-res probabalistic

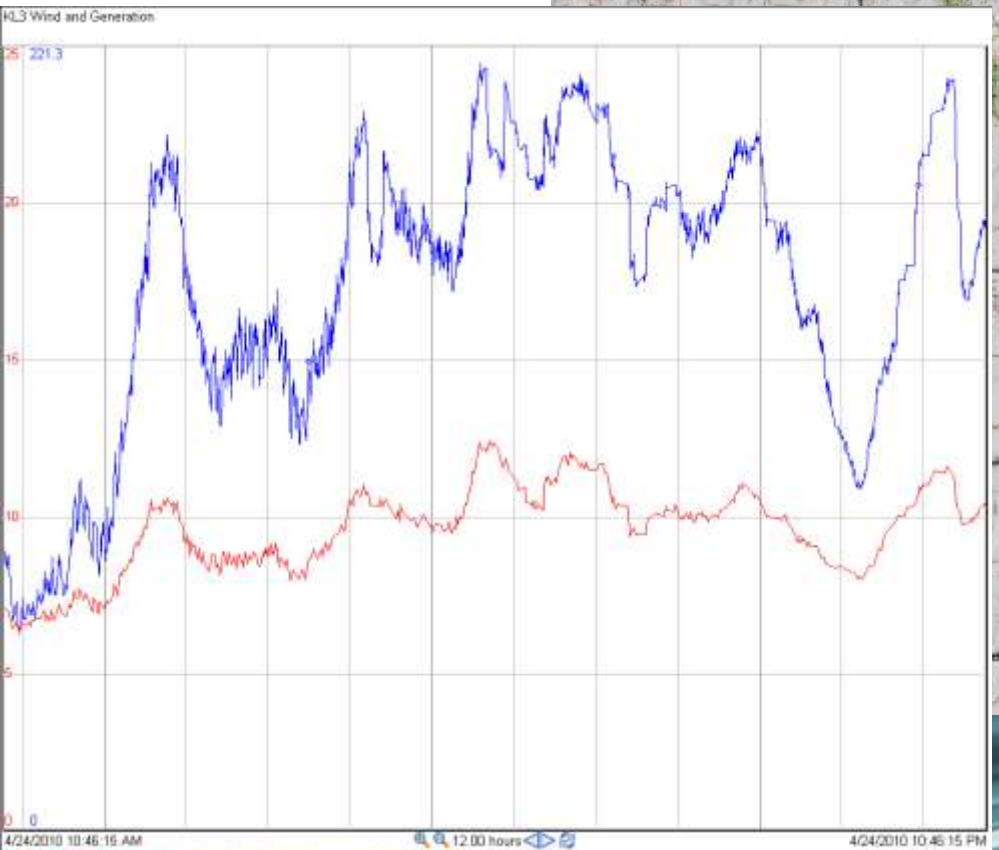
Challenges: Data, data (vertical), assimilation, resolution (horiz and vert), ensembles and post-pro, parameterizations

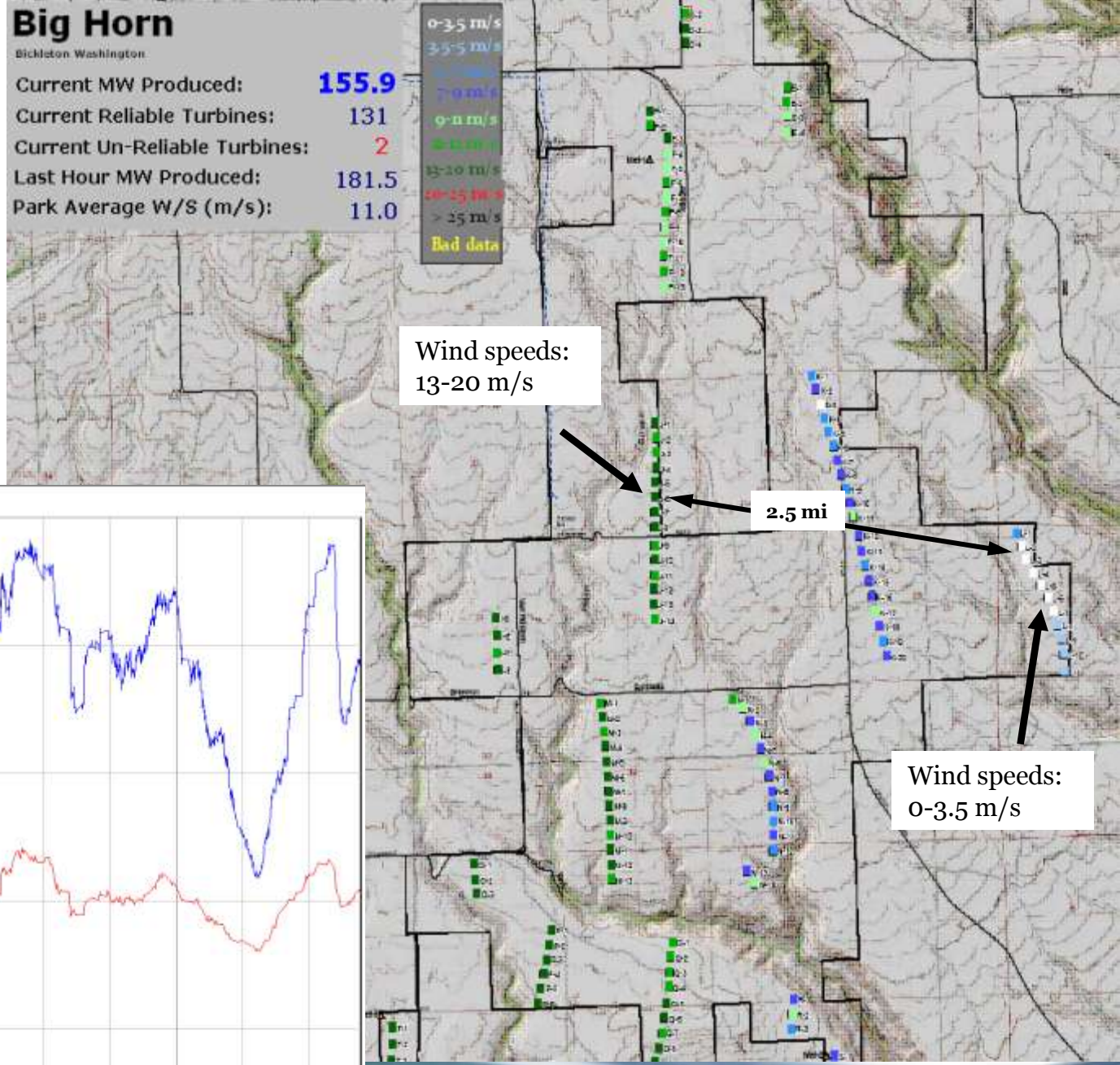




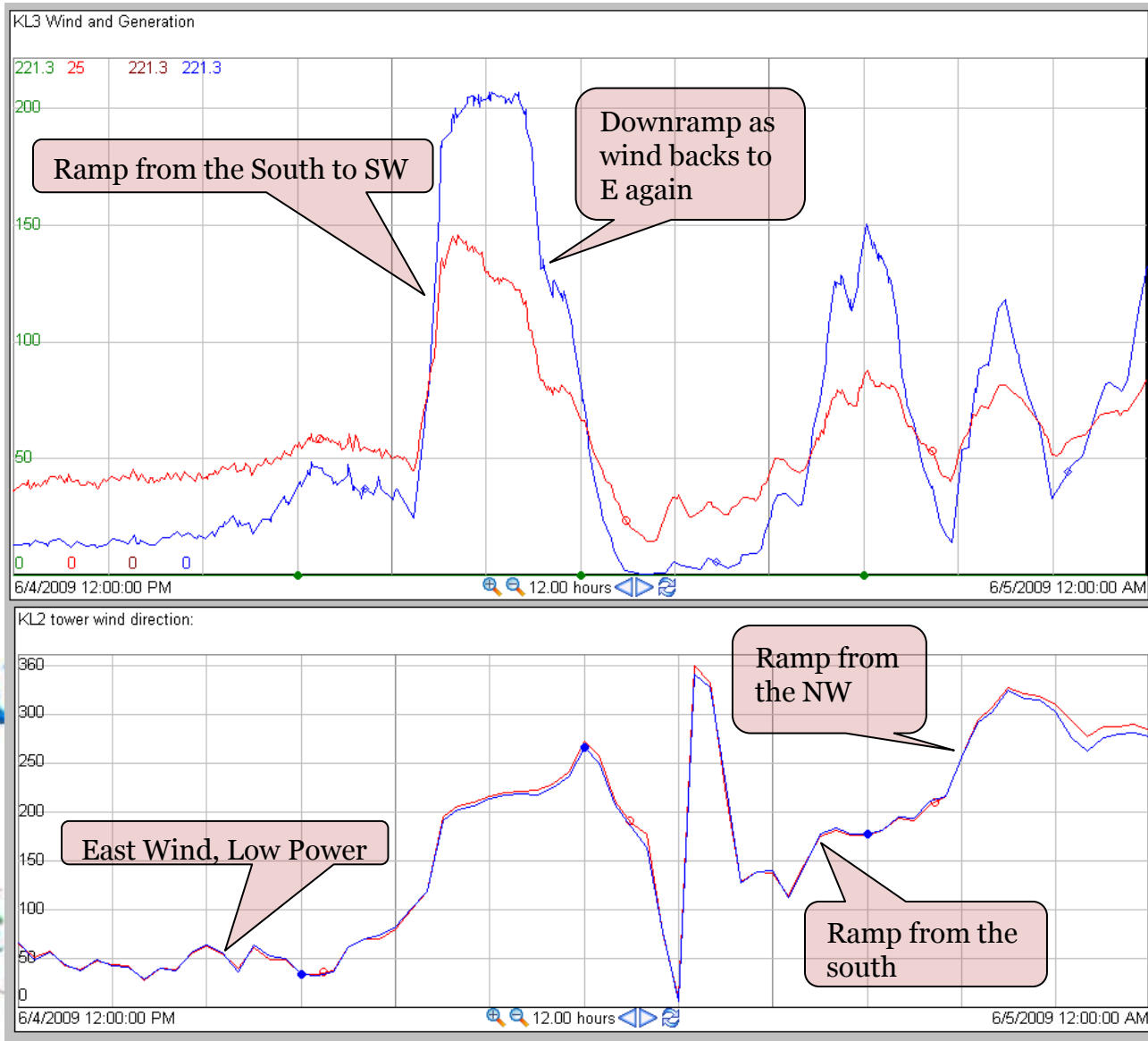
Hi-res deterministic model identifies phenomenon but not details

Mountain waves – park details

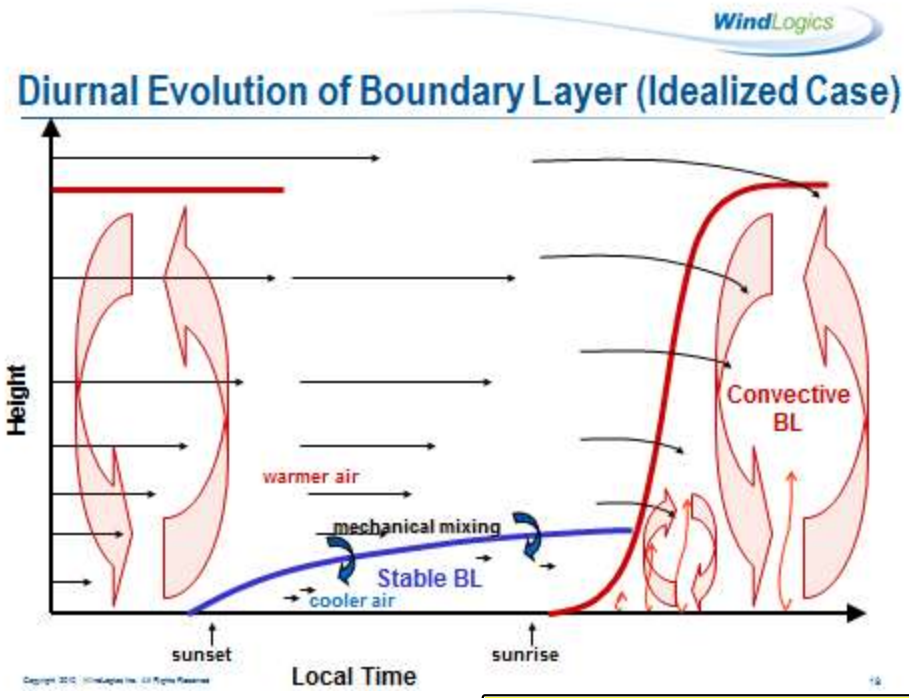




Thunderstorm Outflows



Vertical Mixing and Boundary Layer Processes



- Diurnal heating/cooling cycle
  - Huge role in wind energy
  - Some effect on solar
- Mechanical mixing/turbulence
- Forecasting vertical mixing is very difficult:
  - Got to get surface right (soil, snow, moisture, land use)
  - Got to get the PBL right
  - Got to get the clouds right
  - Got to get the winds aloft right!
  - i.e. the top NWP problems

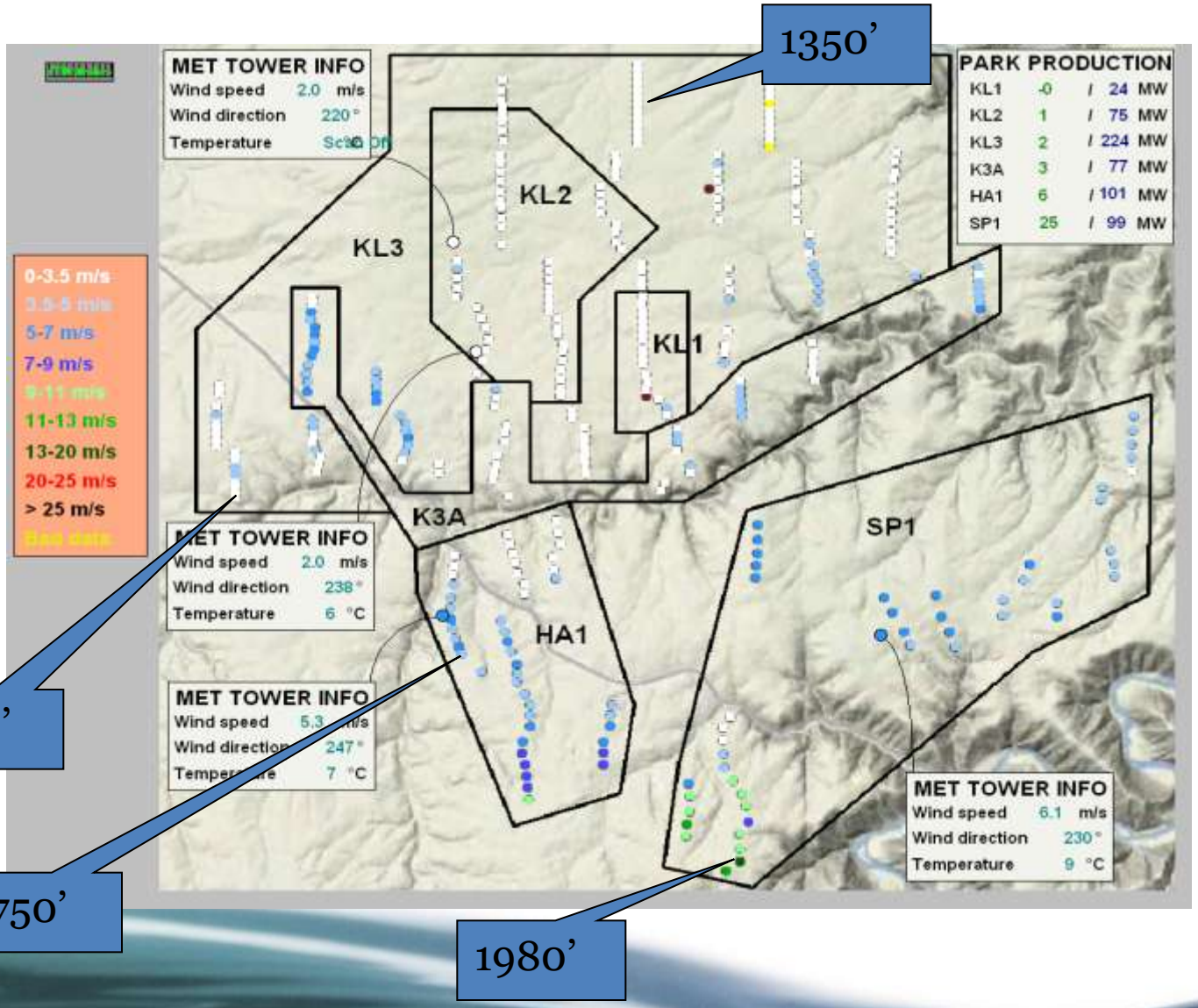
BIG DEAL? YES

See Next Slides

An Example of Warm Sector Mixing in Terrain

5:22 PDT

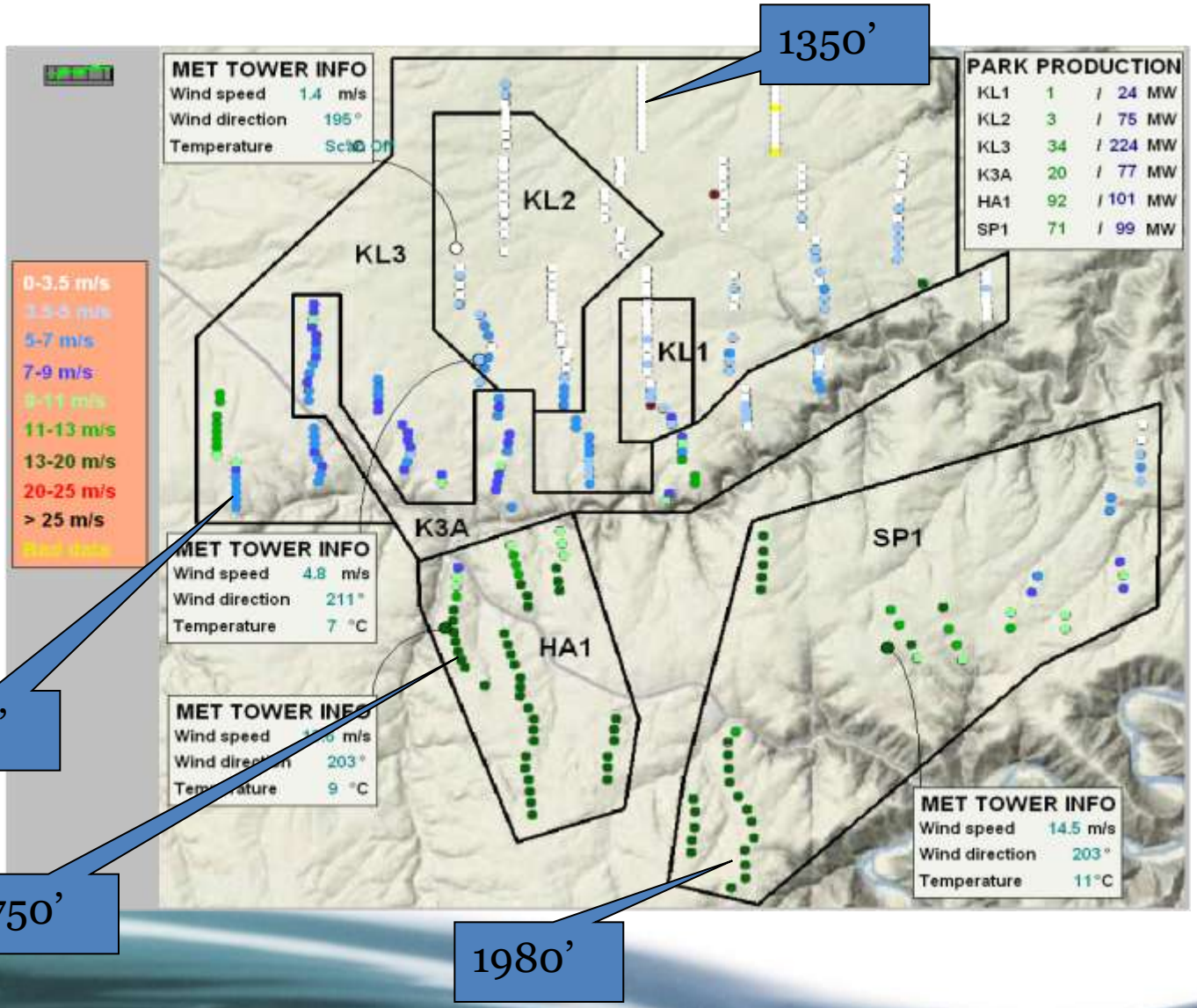
Most production is confined to highest elevations where some turbines see almost full output



An Example of Warm Sector Mixing in Terrain

6:22 PDT

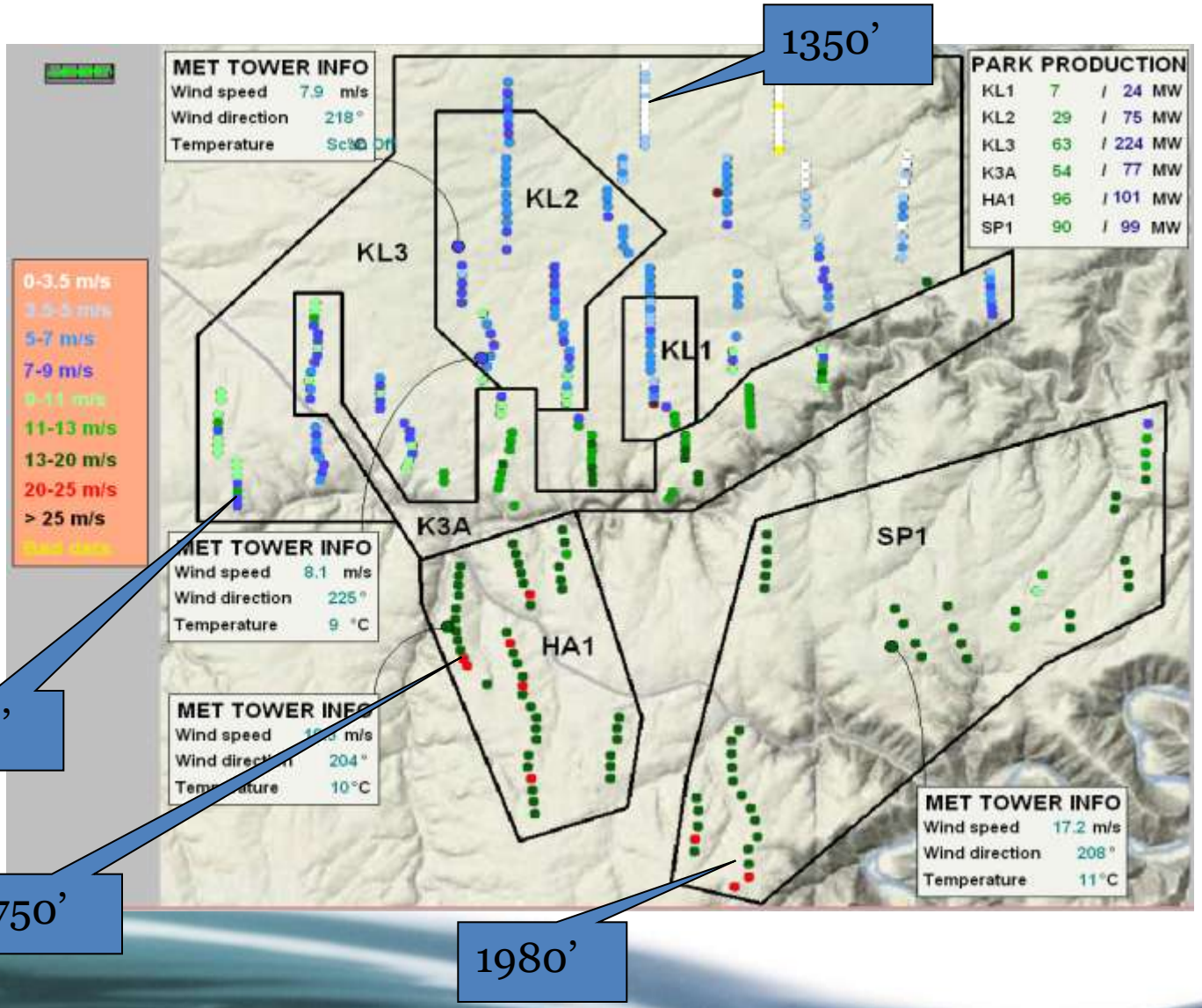
Production has spread throughout the higher parts of the wind farm, but low elevation turbines still aren't at cut in speeds



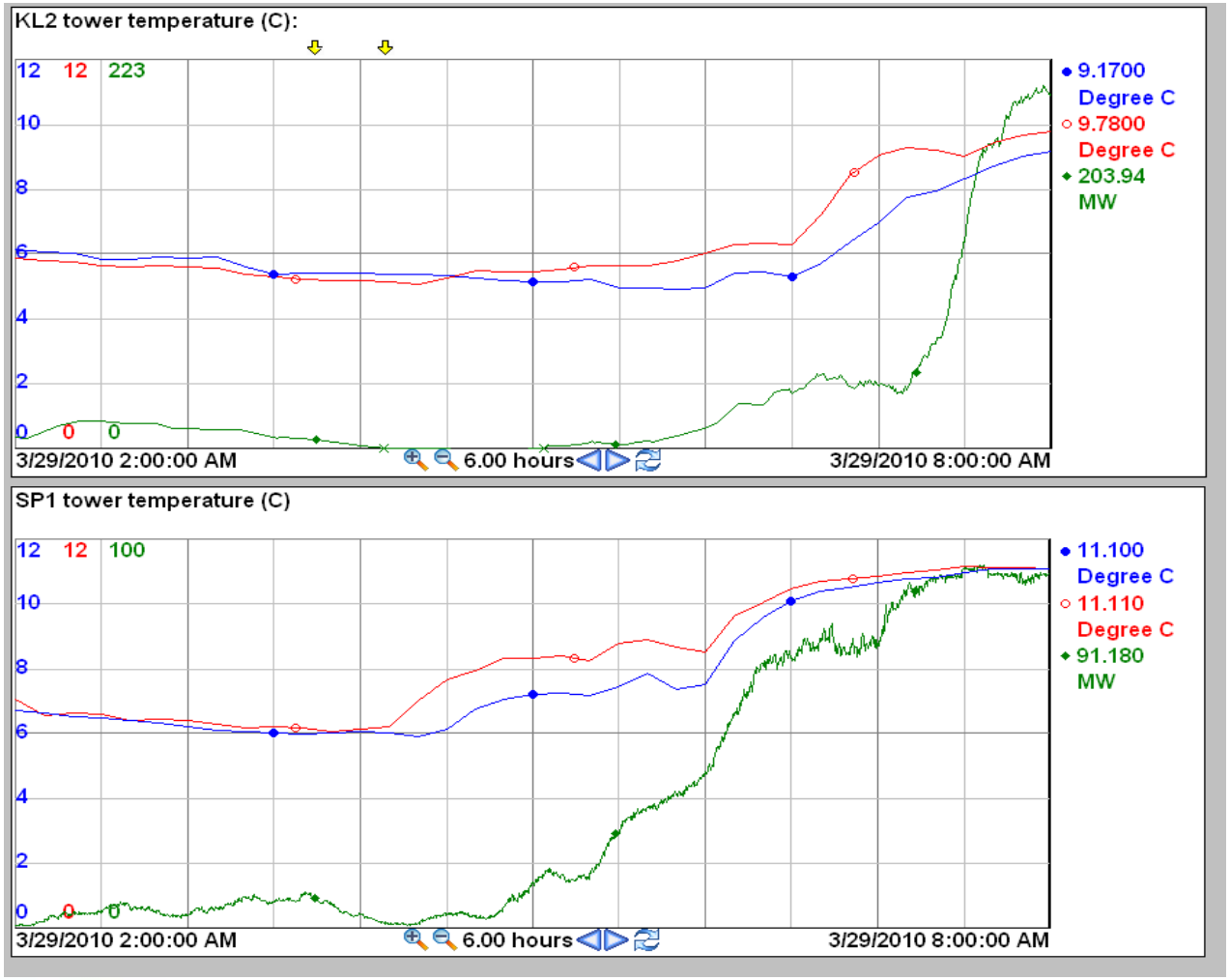
An Example of Warm Sector Mixing in Terrain

7:22 PDT

Turbines in higher elevations are close to cut out, but low elevation rows still haven't cut in!



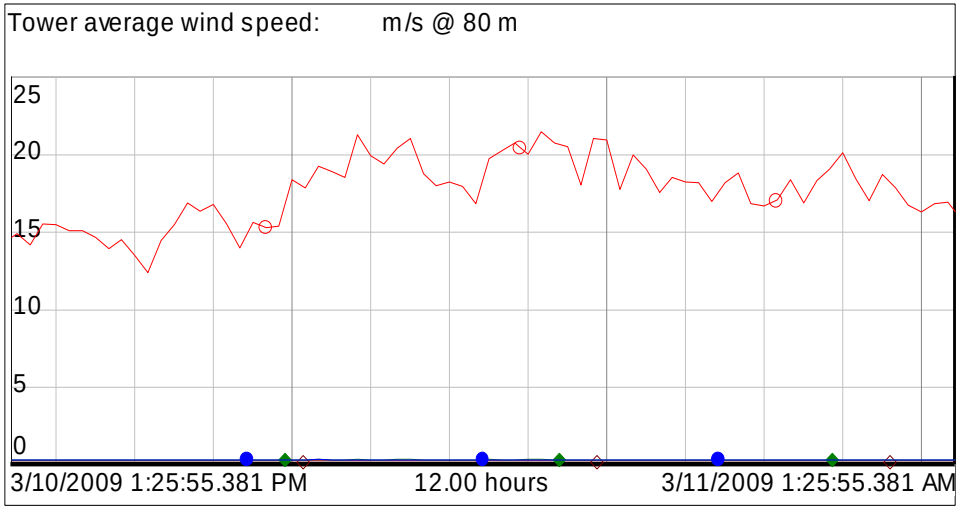
Time series view of temperature and power output at the north (low elevation) and south ends of the facility



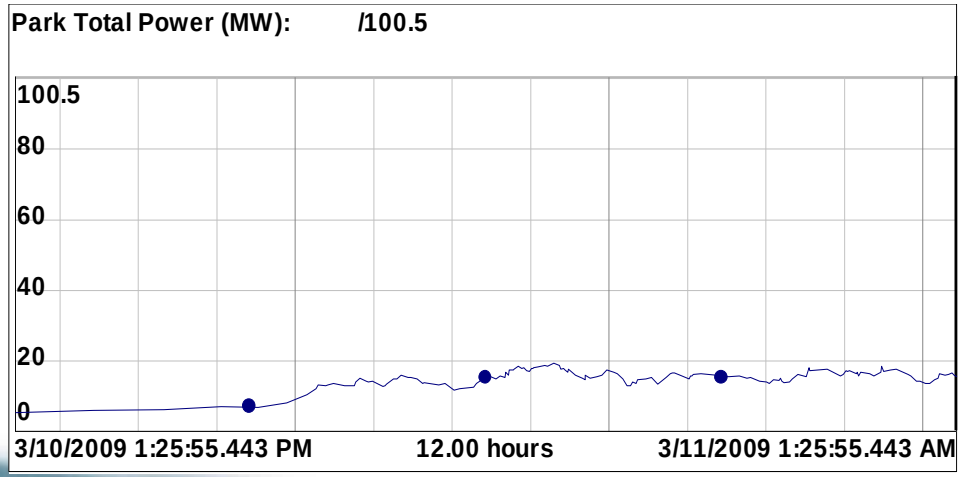
This was just one example.

Mixing related forecast errors occur all the time in association with numerous phenomena at all scales

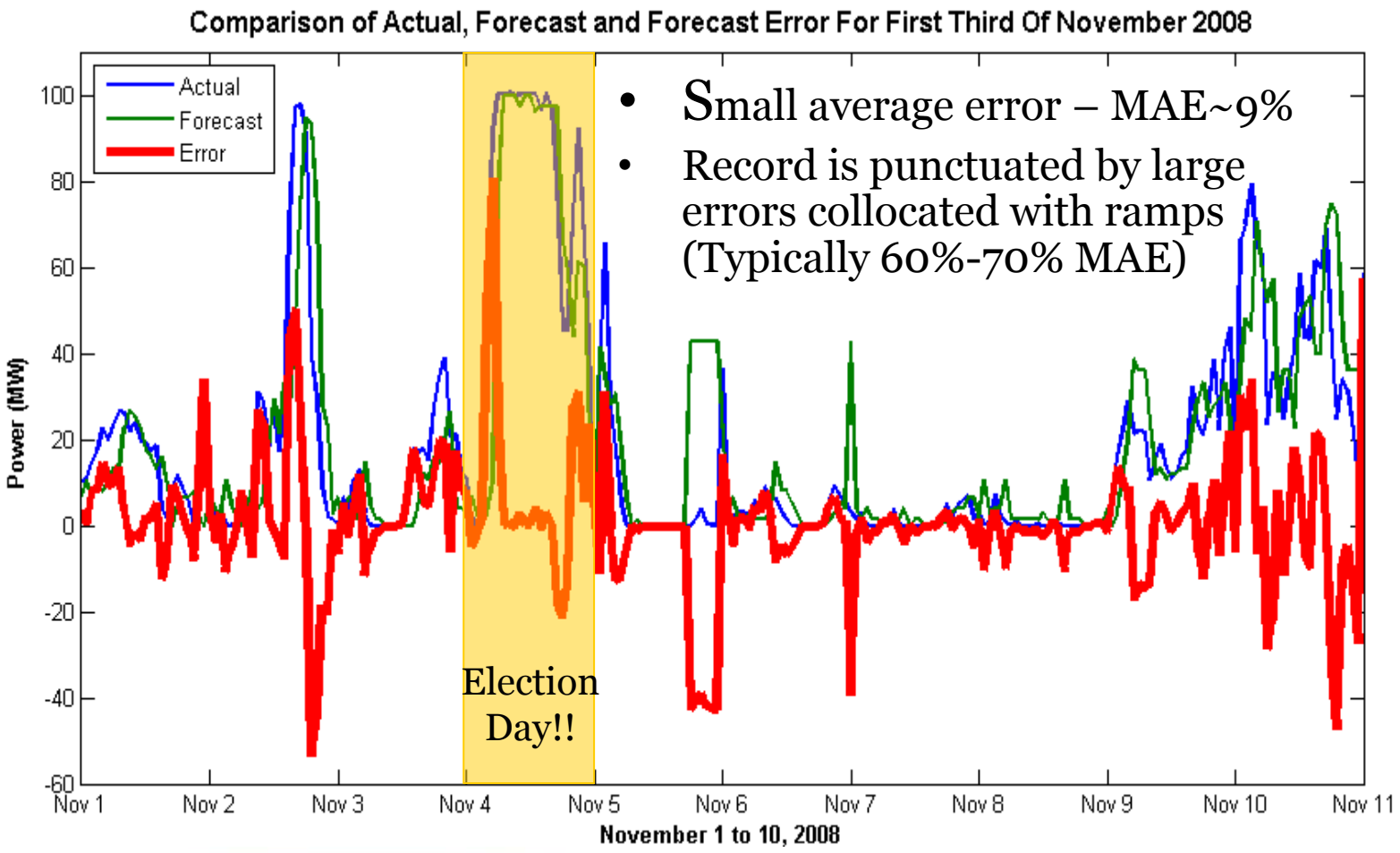
Down Ramps Due To Extreme Weather



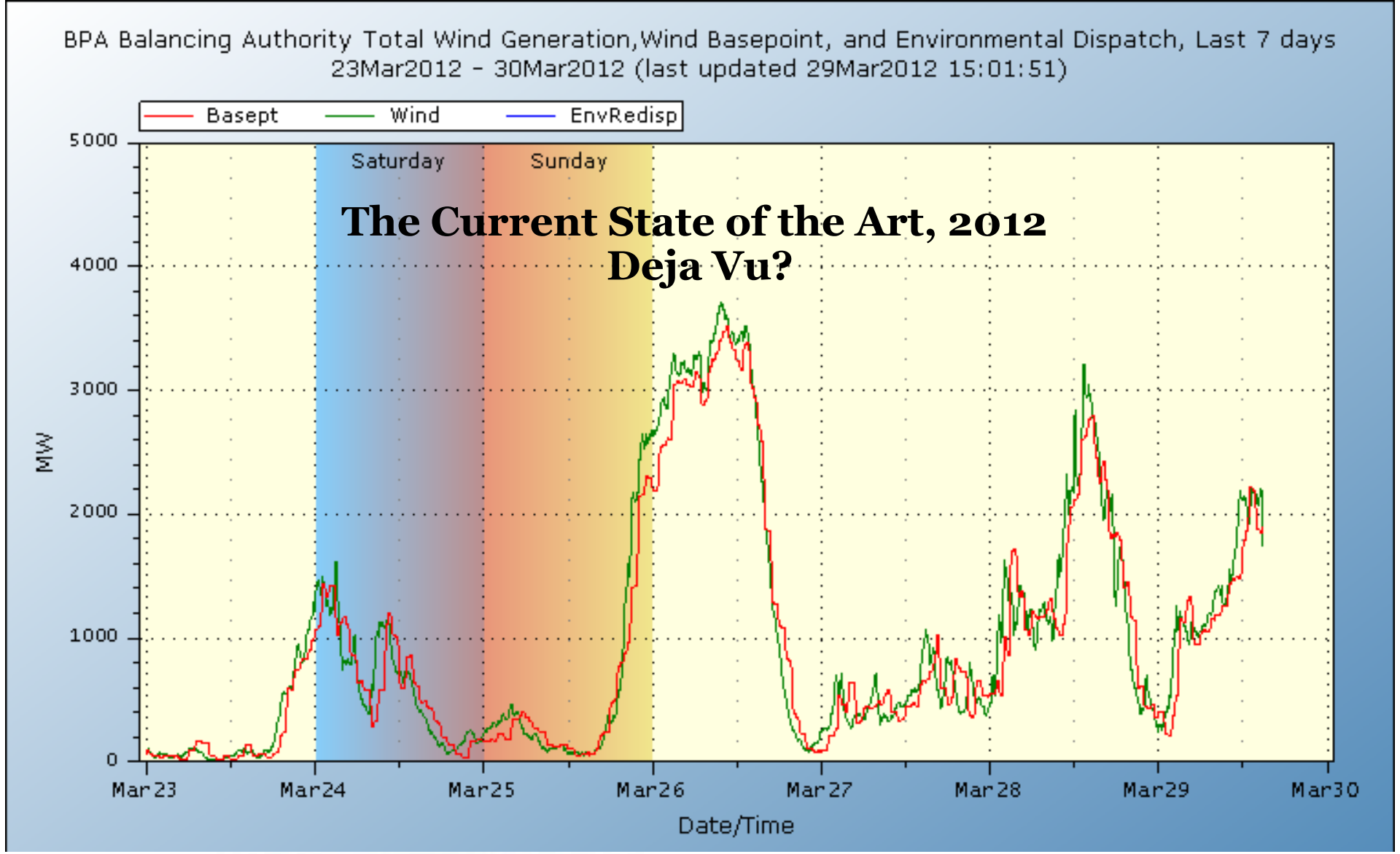
- High wind cut out and icing are the threat
- High and low temperatures can also be an issue
- Typically “slow” events
- But can have very large economic impact



The Current State of the Art



- Small average error – MAE~9%
- Record is punctuated by large errors collocated with ramps (Typically 60%-70% MAE)



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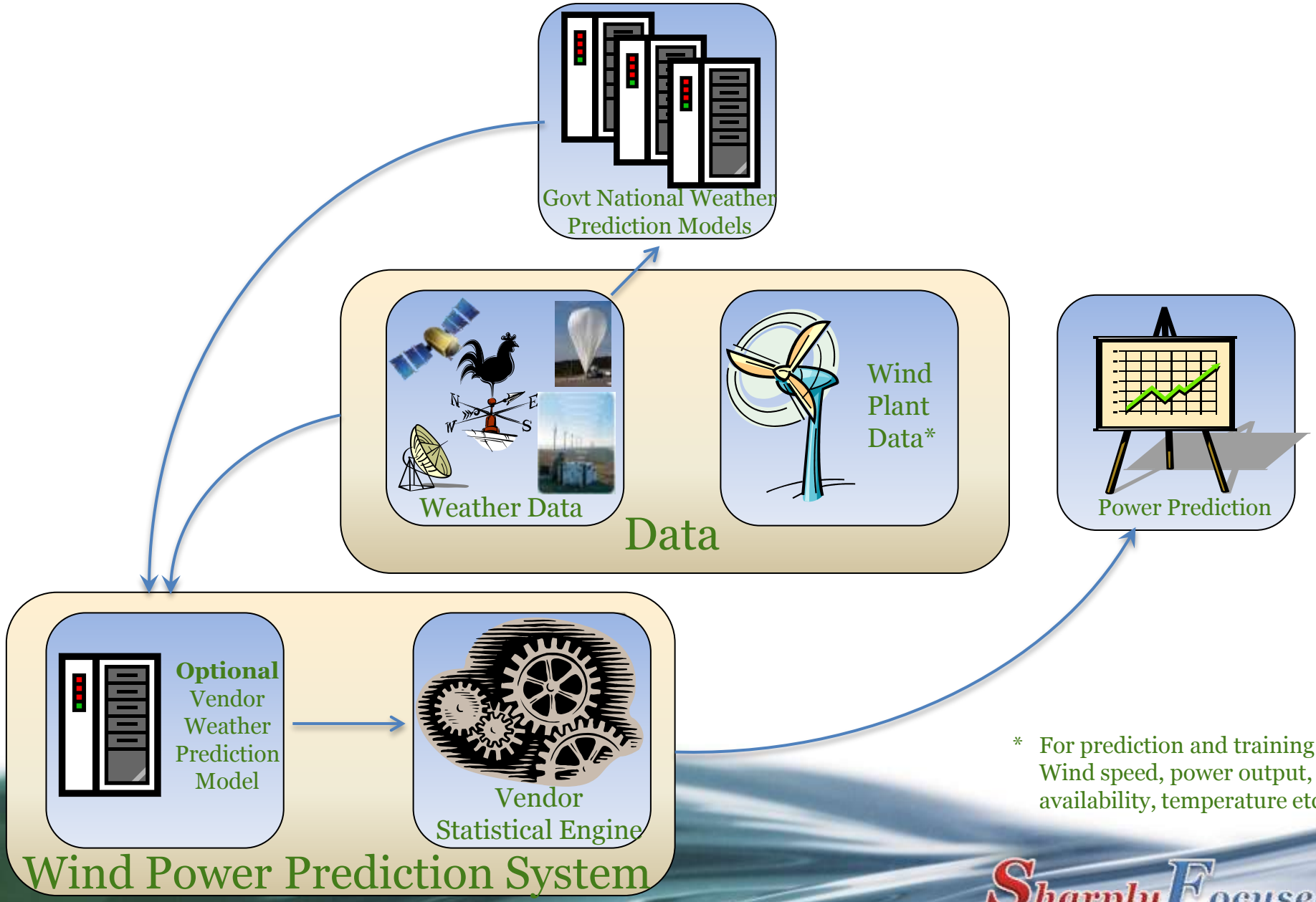
Wind Forecasting 101



* For prediction and training Wind speed, power output, availability, temperature etc

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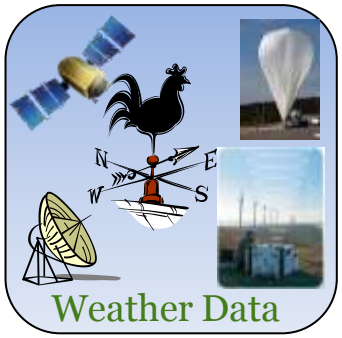
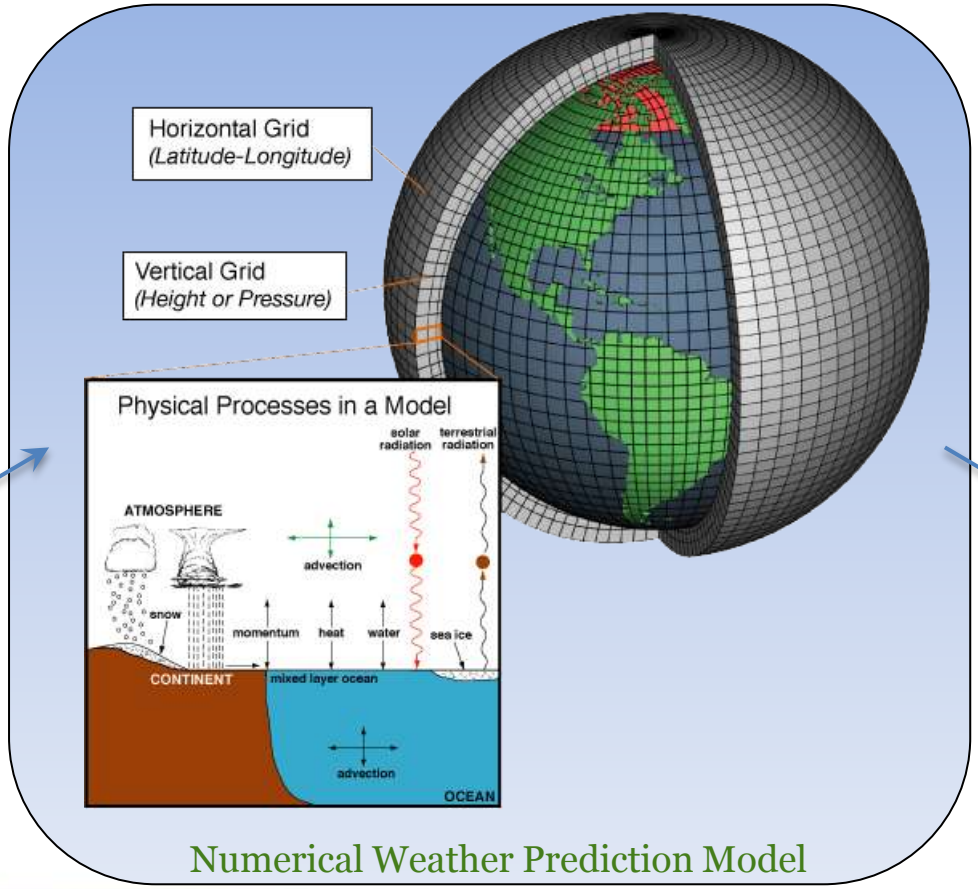
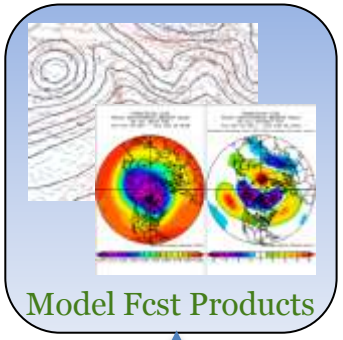
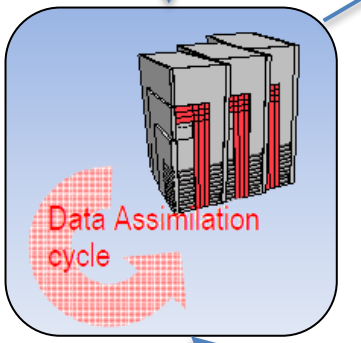
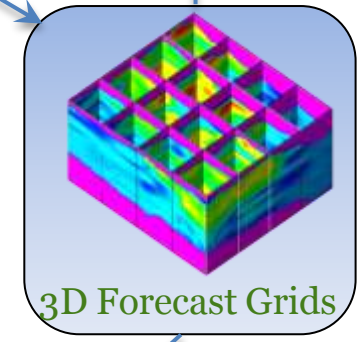
Foundational Numerical Weather Prediction





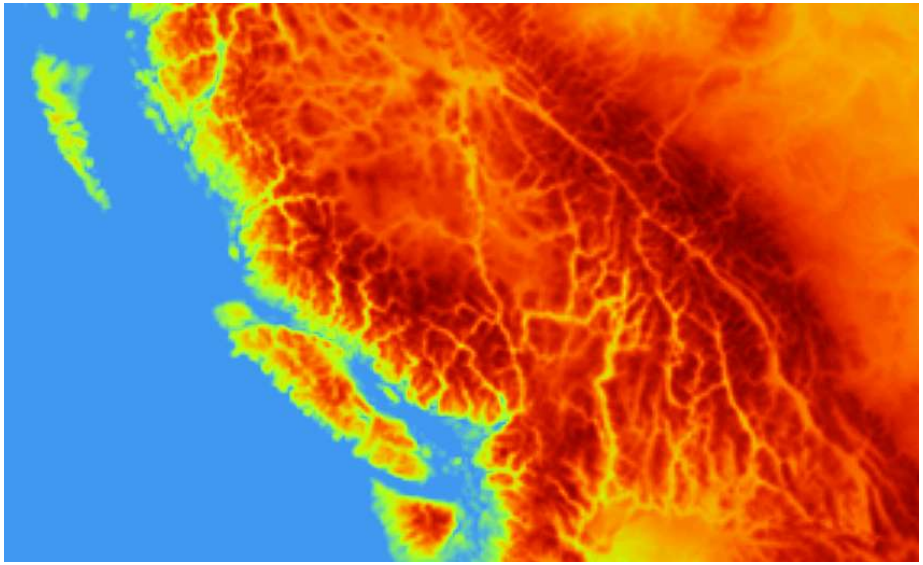




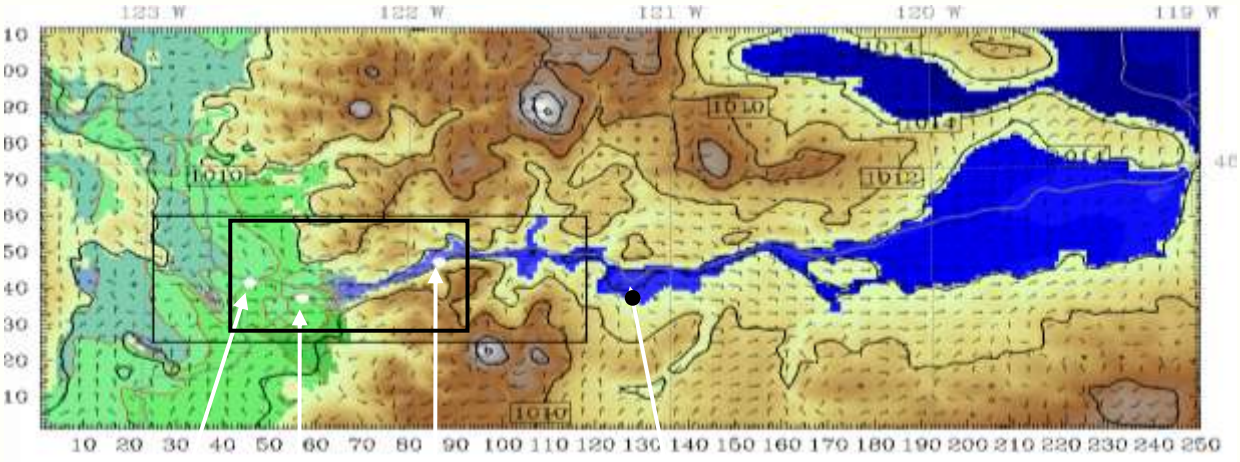


Model Resolution and Its Consequences

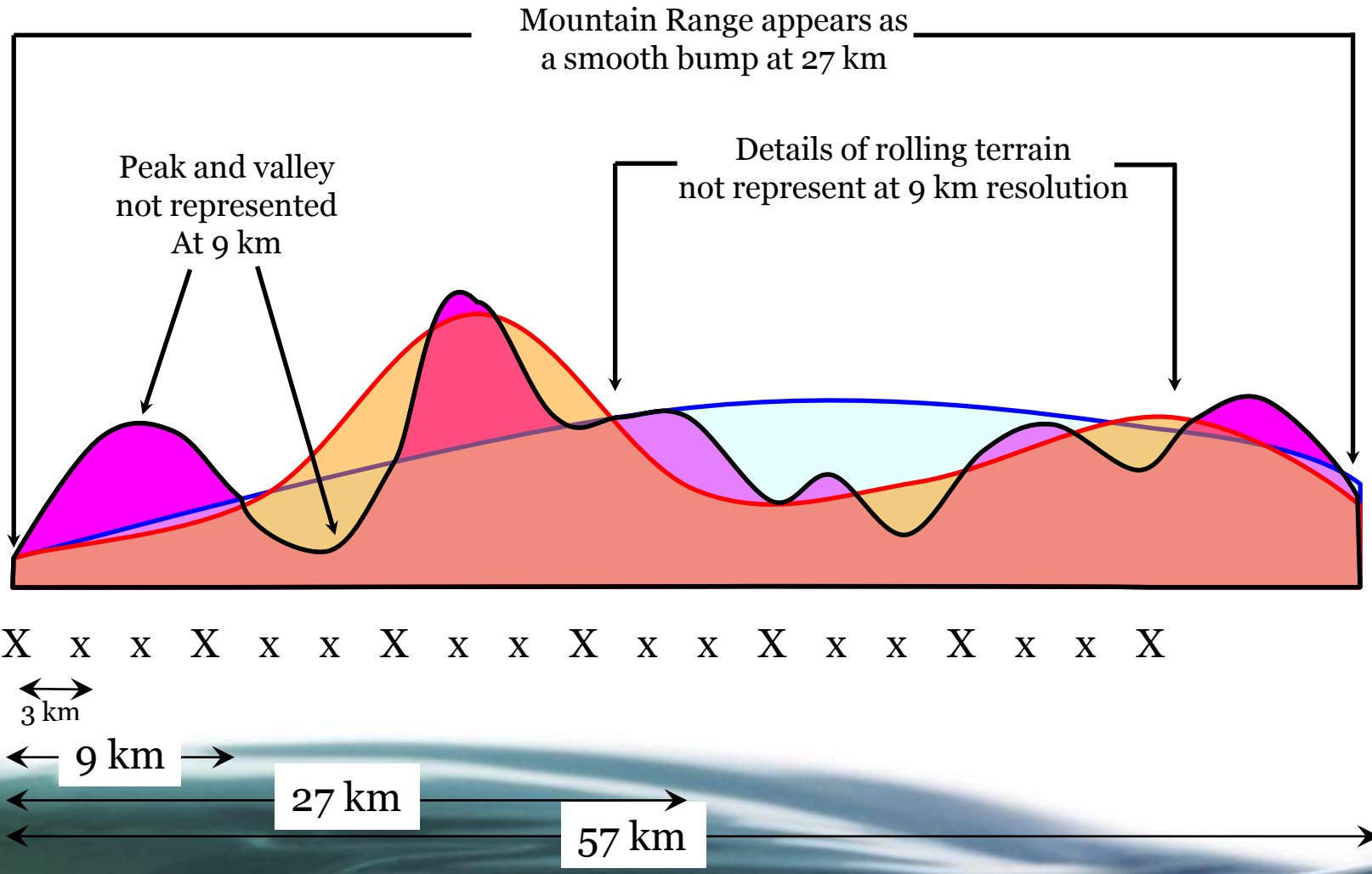
- Where is this?
- What about this?
- Unresolved terrain means unresolved surface characteristics and physical processes



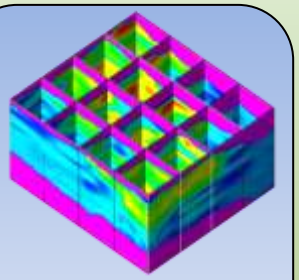
1.33 km grid spacing, Pass Height = 150 m



Example Of Effect Of Model Resolution On A Mountainous Terrain Cross Section



Wind Power Forecasting System Detailed View



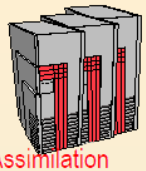
3D NWP Forecast Grids and Post-Processed Data

Weather Data

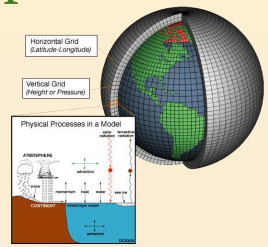
Plant Data

Transmission constraints, current capacity, output, weather etc

Optional NWP Layer



Typically regional scale to downscale foundational forecasts
Data assimilation is currently unusual here



Optional NWP Post Processing

Attempts to get the best weather forecast possible to use as an input in power forecasting by removing model biases

Power Forecasting Engine

Creates power forecast and confidence intervals based on statistical (often proprietary) methods (neural net, SVM etc)
Utilizes plant and weather data to tune the forecast to current conditions

Statistical Relationships

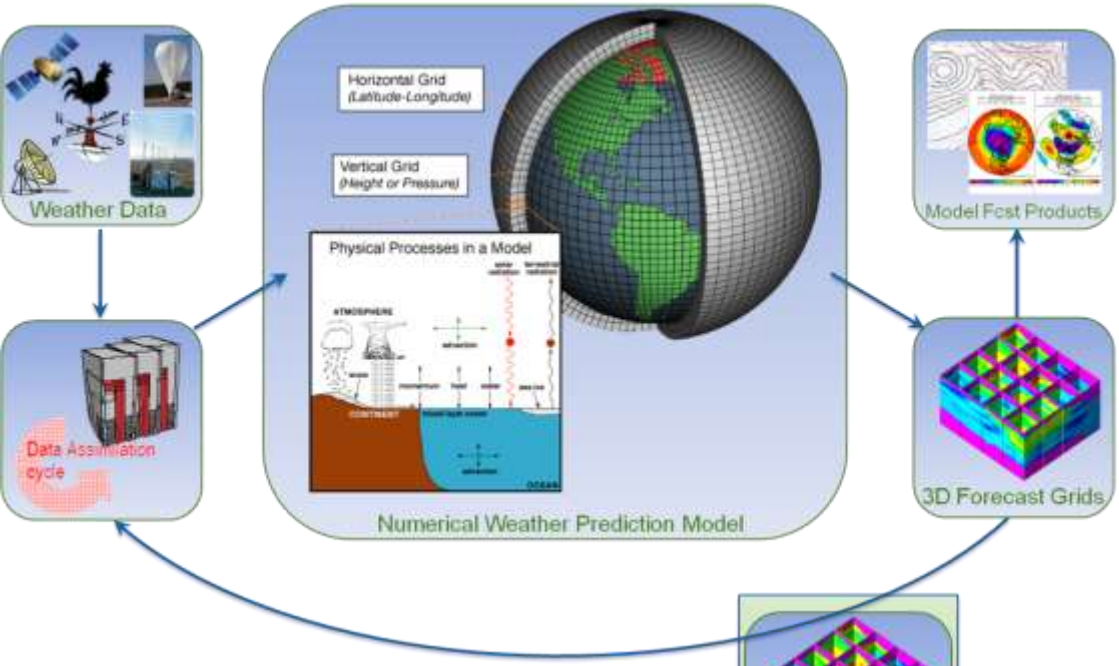
<u>Examples:</u>

- NWP forecast to actual weather
- Output to weather
- Output to NWP

Training Layer

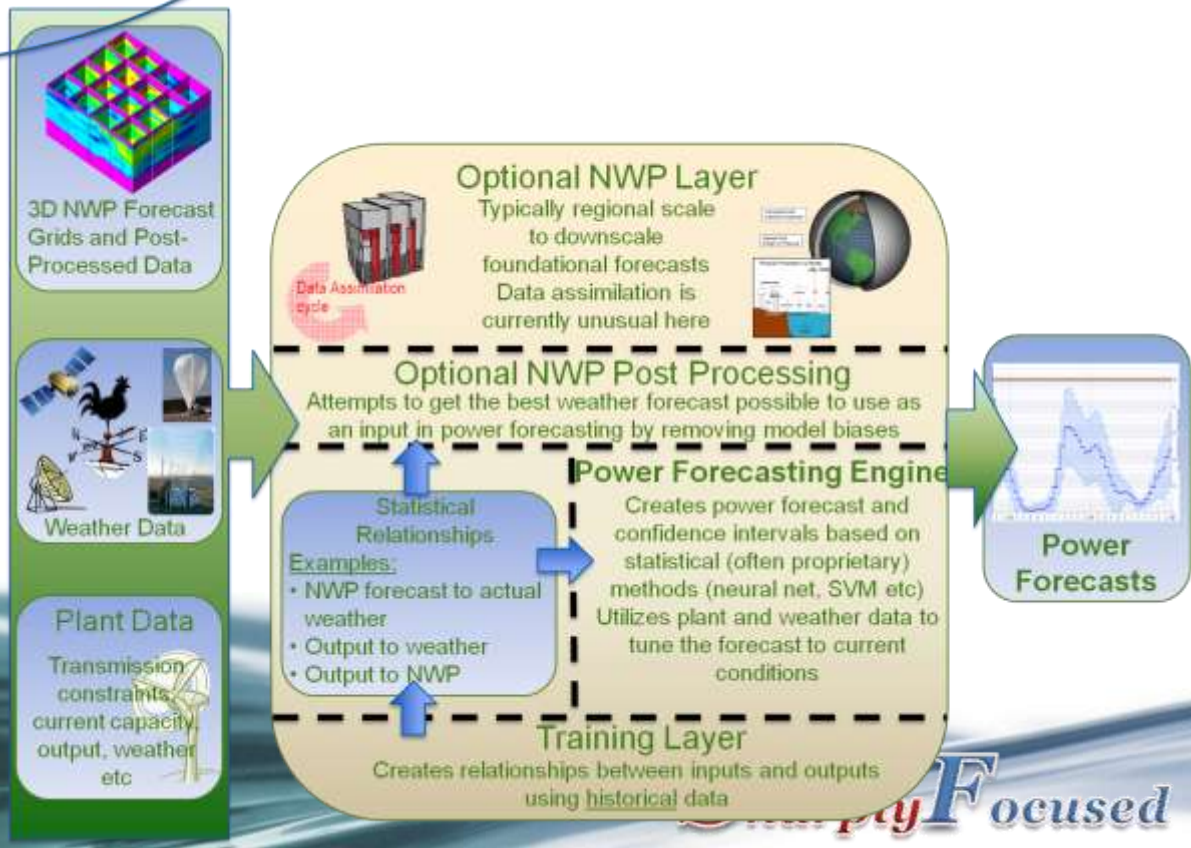
Creates relationships between inputs and outputs using <u>historical</u> data

Power Forecasts



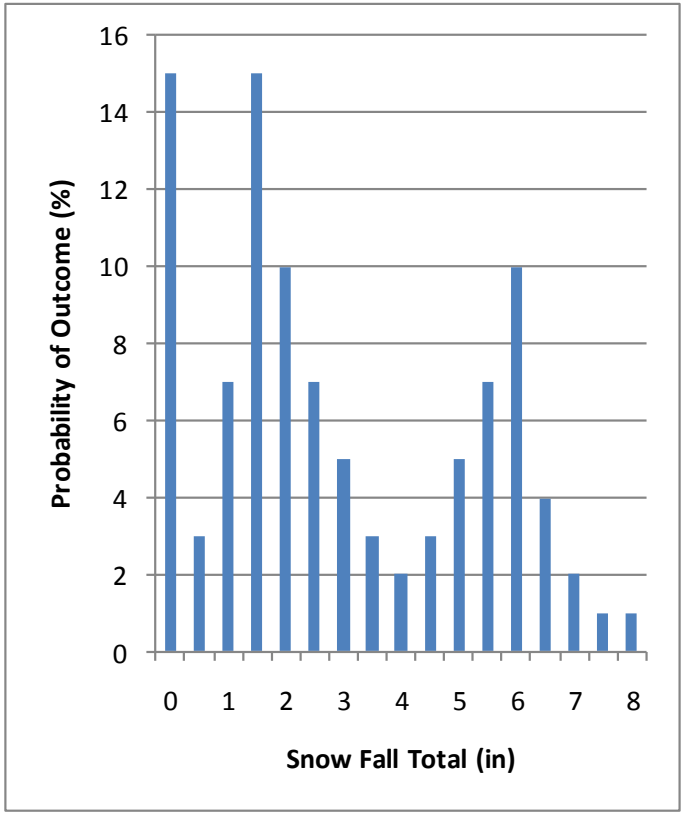
What Data Is Needed? What For?

Do BA's need centralized forecasts? Do generators need facility forecasts?



Wind Power Forecasts Need To Resolve Local Scale Processes

- Computational requirements are at least cubic as a function of resolution before considering vertical resolution
- Smaller scale physical processes occur on smaller time intervals
- Higher resolution implies more data needed for initial conditions, boundary conditions and verification



And Capture the Variability and Uncertainty Statistically

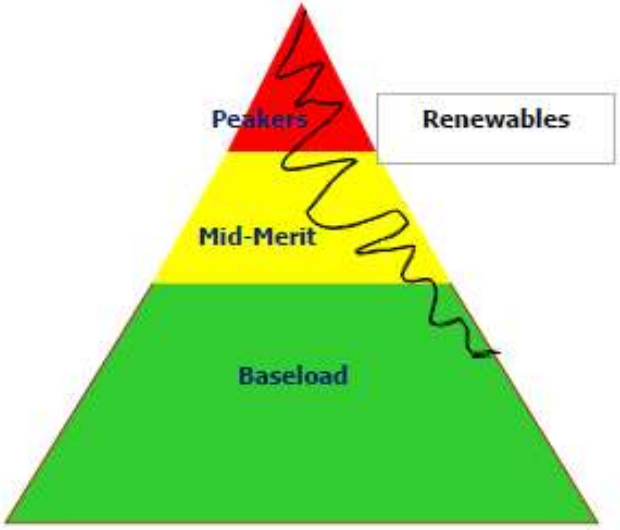
- Ensemble forecasts are needed to encapsulate truth and place statistical likelihood on different outcomes
- Methods to integrate variability and uncertainty information into decision support are needed

VERS Will Lower Costs If Properly Integrated

- All generation types have costs, benefits and challenges
- Current operating practices are optimized around thermal generation
- VER challenges are different. Ramming the square VER peg in the round hole of the current system is inefficient at best.
  - Market/system redesign is needed
- There SHOULD be the price associated with VER variability
  - BUT also a price associated with the cost of every other generator
- Similarly incentives should be provided to maximize generator benefits
- The value of forecasting is inextricably linked with system design
  - The value of forecasting at different horizons and the vision of where forecasting is going should be a core component of system design

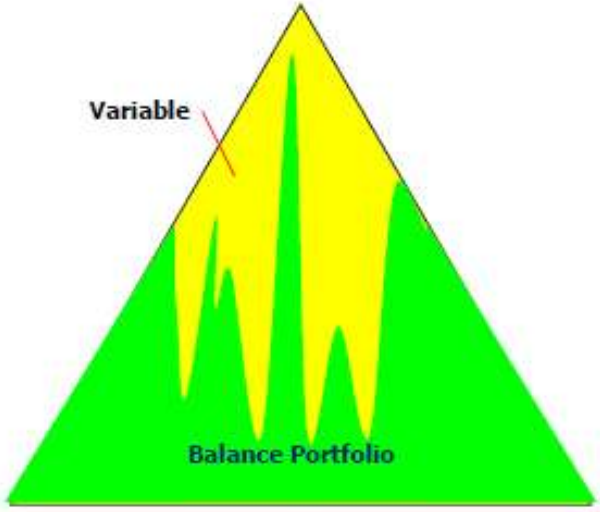
Loads and Resources – A New Paradigm

RE Forecasts are nice but don't affect operations
RE is must-take
Fossil-based facilities operate to a define duty
New facilities chosen for least-cost energy



Traditional Utility Paradigm (w/ some RE)

RE Forecasts drive operational decisions
RE is dispatchable
Fossil-based facilities are modified for flexible duty
New facilities chosen for least-cost energy w/ flexible optionality



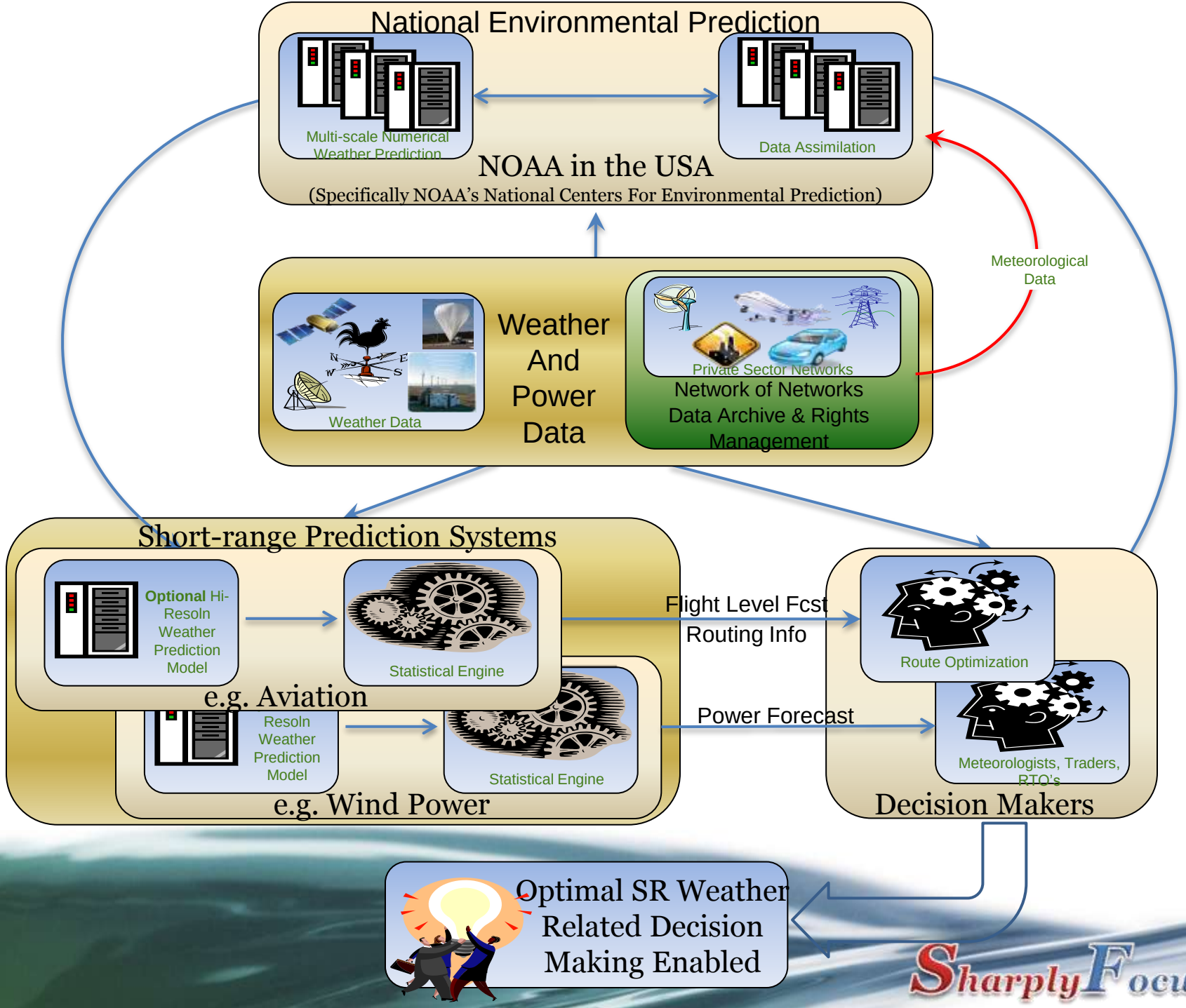
High Penetration Portfolio

Taking Forecasting To The Next Level

- Renewable energy (in particular wind) forecasts today are driven by:
  - Relatively low resolution forecast model output with 6-hour or longer cycle time obtained from public sources. These are not sufficient for the job!
  - Limited observations that drive statistically based black boxes in the 0-6 hour range
- A step change in skill can occur especially in the short time horizon (3-12 hrs) if:
  - Observing remote sensing technologies are developed and deployed that can capture large enough samples of the atmosphere to provide data needed for high resolution assimilation, verification, bias correction and model development
  - Operational data assimilation systems are brought up to current-state of the art while prioritizing R&D in this area
  - High resolution cycling models, initialized and constrained with all available data are deployed ideally in ensembles
  - Models are improved to address inadequacies that impact boundary layer process and accuracy
  - Way to properly quantify uncertainty and variability are developed. Without so much is left on the table

The Road Less Traveled

- These are huge challenges
  - Too big for forecast vendors. Too risky and specialized for generators. Too expensive for ISO's. Nobody wants to invest until the ROI is clearer. Right now it is as clear as mud.
- But this is all doable and is some low hanging fruit to aid wind integration – its just needs a kick start
- And the result will have huge benefit to other sectors too
  - Transportation, air quality, Homeland Security etc



Summary/Priorities

- Short range forecasting is a data driven problem
  - Advance remote sensors
  - Advance data assimilation
  - Advance rapid cycling high resolution modeling techniques
- Accept that a "Perfect Forecast" is impossible
  - Yes, strive towards improvements but…
  - Focus equal effort on ways to create and use reliable variability and uncertainty data
    - Advance ensembles. Make sure output is what "client" needs
    - Advance the tools (for grid operations , trading and asset management) that turn probability data into actionable information
    - Partner and Educate: bridge the divide between atmospheric science, engineering and business
- Model improvement
  - Esp. Stable PBL problem, cloud microophysics
- Synergize – Get buy in and support from other sectors
  - National data infrastructure.
- Bracket the ROI
  - Everyone wants better forecasts but nobody will invest as they can't determine the value.

"And for the sake of our economy, our security and the future of the planet, I will set a clear goal as President. We will finally end our dependence on oil in the Middle East."

Barack Obama

State of the Union Address

January 25, 2011

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